Effects of Organic and Conventional Practices on Weed Control in a Perennial Cropping System

Kendra Baumgartner, Kerri L. Steenwerth, and Lissa Veilleux*

Vineyard weed communities were examined under the influence of an organic weed control practice, soil cultivation with a Clemens cultivator, and applications of the herbicide glyphosate. Experimental treatments (winter–spring glyphosate, spring cultivation, fall–spring cultivation, fall cultivation–spring glyphosate) were carried out in a California wine grape vineyard for 3 yr. Cultivation alone was not as effective as glyphosate, based on lower weed biomass in the glyphosate-only treatment in 2 of 3 yr. However, given that two passes with the Clemens cultivator decreased weed biomass relative to one pass, it is possible that additional passes could bring about further reductions. Pairing fall cultivation with glyphosate was as effective at reducing weed biomass as two glyphosate applications in 2 of 3 years, suggesting that substituting a glyphosate application with cultivation may be an effective method of reducing herbicide use in vineyards. Canonical correspondence analysis revealed significant treatment effects on community structure. Weed composition in the spring cultivation treatment was significantly different from that of all other treatments. Based on our findings of high relative abundance of field bindweed and sowthistle species, which are problematic vineyard weeds that grow into the vine canopy and disrupt canopy management practices, it is possible that either the presence of soil disturbance or the absence of herbicides favored these species.

Nomenclature: Glyphosate; annual sowthistle, *Sonchus oleraceus* L. SONAL; field bindweed, *Convolvulus arvensis* L. CONAR; spiny sowthistle, *Sonchus asper* (L.) Hill SONAS; wine grape, *Vitis vinifera* L. 'Merlot'.

Key words: Clemens cultivator, perennial cropping system, tillage, vineyard, weed community.

Organic wine grapes are gaining popularity among winemakers and the public in Europe (Willer and Zanoli 2000). Their popularity in the United States is evidenced by the fact that grapes represented 10% of 2002 organic commodity sales in California (Klonsky 2004), which produces 88% of U.S. grapes (Anonymous 2006b). U.S. acreage of organic vineyards has increased substantially over the past 15 yr, and currently represents 1.5% of the total grape acreage, 90% of which is located in California (Green and Kremen 2003). Rising acreage of organic vineyards in the United States may be driven, in part, by passage of more stringent water-quality regulations in California (Anonymous 2006a). These higher standards for water quality mitigate pollution from agricultural runoff by restricting pesticide use, thereby forcing growers to use different pesticides, to limit pesticide applications, or to adopt organic practices.

A growing list of herbicide-resistant weeds (Basu et al. 2004) makes it clear that repeated use of a single tactic for pest control not only leads to a preponderance of the most problematic species, but can fundamentally shift the genetic composition of their populations. Integrated weed management (IWM) emphasizes the use of multiple tactics to address the causes of weed problems, rather than simply reacting to weed infestations (Buhler 2002). Cardina et al. (1999) outline various levels of IWM, which start with individual weed control practices and progress to the integration of practices. Liebman and Gallandt (1997) also emphasize a multistrategy approach and its incorporation into the cropping system, given that weeds are responsive not only to weed control, but also to numerous facets of crop production.

IWM in California vineyards typically involves the integration of postemergence and preemergence herbicides (Agamalian 1992), with less emphasis on incorporation of nonchemical methods. This practice reflects, in part, the paucity of published research on weed control in organic vineyards. The few examples of weed research that pertain to vineyards focus on herbicides (Kadir and Al-Khatib 2006; Monteiro and Moreira 2004). Research on IWM in vineyards and other perennial cropping systems lags far behind that of annual systems (e.g., Cardina et al. 2002; Legere et al. 2005; Menalled et al. 2001; Shrestha et al. 2002). As such, there is a need for research on nonchemical practices for vineyards, to minimize the negative impacts of wine grape production on public-trust resources.

The aim of this research was to compare the organic weed control practice, soil cultivation, to the conventional practice, applications of the herbicide glyphosate, in a perennial cropping system in northern California. Investigation of glyphosate and cultivation within a wine grape production system is warranted because the deficit irrigation and fertilization practices used purposely to devigorate the vines, as low yields are associated with high wine quality, are unique among cropping systems. Infrequent irrigation and the typical absence of precipitation during the grapevine growing season mean that weed growth is restricted primarily to winter and spring, which allows for minimal weed control attempts. Nonetheless, weed establishment is minimized on the vineyard floor beneath the vines in order to prevent weed shoots from growing into the vine canopy, where they interfere with the numerous, labor-intensive, canopy management practices. Objectives were (1) to evaluate the efficacy of the practices in reducing weed biomass; (2) to characterize the weed community; (3) to monitor vine yield, growth, and nutrition under the influence of the practices; and (4) to determine the effects of the practices on soil biological activity. Our intent in monitoring vine and soil parameters was to identify effective weed control practices that can be integrated into the cropping system without impacting wine grape production.

Table 1. Weed control practices associated with experimental treatments.

Treatment	Practice	Practice dates 2003	2004	2005
Fall–spring cultivation	Cultivation	November 27, 2002	November 24, 2003	December 3, 2004
	Cultivation	May 16, 2003	April 20, 2004	May 7, 2005
Fall cultivation–spring glyphosate	Cultivation	November 27, 2002	November 24, 2003	December 3, 2004
	Glyphosate (5.6 kg ai ha^{-1})	May 22, 2003	April 27, 2004	May 13, 2005
Spring cultivation	Cultivation	May 16, 2003	April 20, 2004	May 7, 2005
Winter–spring glyphosate	Glyphosate (2.8 kg ai ha^{-1})	February 22, 2003	January 31, 2004	February 11, 2005
	Glyphosate (5.6 kg ai ha^{-1})	May 22, 2003	April 27, 2004	May 13, 2005

Materials and Methods

The experiment was conducted in a commercial wine grape vineyard in the Napa Valley of northern California from 2003 to 2005. The vineyard was established in 1996 with Merlot (clone 314) on 110R rootstock (*V. berlandieri* Planch. × *V. rupestris* Scheele). Vine spacing was 1.8 by 1.8 m, with east–west row orientation. Vines were trained as unilateral cordons to a vertical shoot positioning trellis system. The 0.84-m-wide section of soil in the vineyard row, where treatments were carried out, was level with the soil in between the rows (vineyard middles); vines were not elevated on berms. The vineyard was on Bale soil (fine–loamy, mixed, thermic Cumulic Ultic Haploxeroll).

There were four treatments: winter–spring glyphosate, spring cultivation, fall–spring cultivation, and fall cultivation–spring glyphosate (Table 1). Glyphosate[1] was applied with a tractor-mounted, 1.2-m-wide, boom sprayer with two fan-type nozzles directed beneath the vines on both sides of the tractor. Cultivations were done with a Radius Weeder[2] (Clemens cultivator), which consists of a 0.3 by 0.1-m metal blade positioned perpendicular to the direction of tractor movement. When inserted slightly below the soil surface, it severs weed shoots from their roots. An automatic articulating arm directs the cultivator around vine trunks and trellis system posts. Because the Clemens cultivator mounts to one side of the tractor, each cultivation required two passes per row. Glyphosate is a common herbicide in wine grape vineyards, and is typically applied twice per season (once at budbreak, once after removing trunk suckers in late spring). Cultivation is a common weed control practice in organic vineyards, where the use of pesticides is forbidden. Frequency of cultivation varies depending on the type of cultivator, but is typically infrequent in summer, as the resulting clouds of dust settle on the leaves, leading to spider mite infestations.

Treatments were arranged in a randomized complete block design with five blocks (0.27 ha per block). Weed control practices were applied to three adjacent vineyard rows; data were collected from the center row. A no-till cover crop of zorro fescue (*Vulpia myuros* var. *hirsuta* Hack.) was maintained in the vineyard middles. The cover crop was reseeded in October 2002 with a seed drill (10 kg ha^{-1}) and mowed every June. Temperature and precipitation were recorded by the nearest California Irrigation Management Information System (CIMIS) weather station (Oakville Station No. 77; Figure 1).

We anticipated that a combination of infrequent, drip irrigation at the study site (85 kl ha^{-1} applied once per week, July to October) and rare precipitation during the growing season would restrict informative weed measurements to early in the growing season. Collection of aboveground weed

biomass was timed in between the last weed control practices and the start of the dry season, and was based on visual observation of peak weed height (June 4, 2003; May 12, 2004; and May 31, 2005). Weed biomass was collected from four randomly placed, 0.6-m^2 quadrats per treatment per block (two at the base of vine trunks, two between adjacent vines), to give a total of 80 quadrats per year. Positioning half of the quadrats at the base of the vine trunks accommodated the fact that the Clemens cultivator is directed away from this section of the vineyard floor so as to avoid damage to grapevine roots. Weeds were sorted by species, dried (70 C, 7 d), and weighed. Volunteer grape seedlings and cover crop seedlings were considered as weeds. Our use of *species* applies to more than one species in the cases of filaree species (*Erodium* sp.) and sowthistle species (*Sonchus* sp.). Several quadrats with plants that shared characteristics of more than
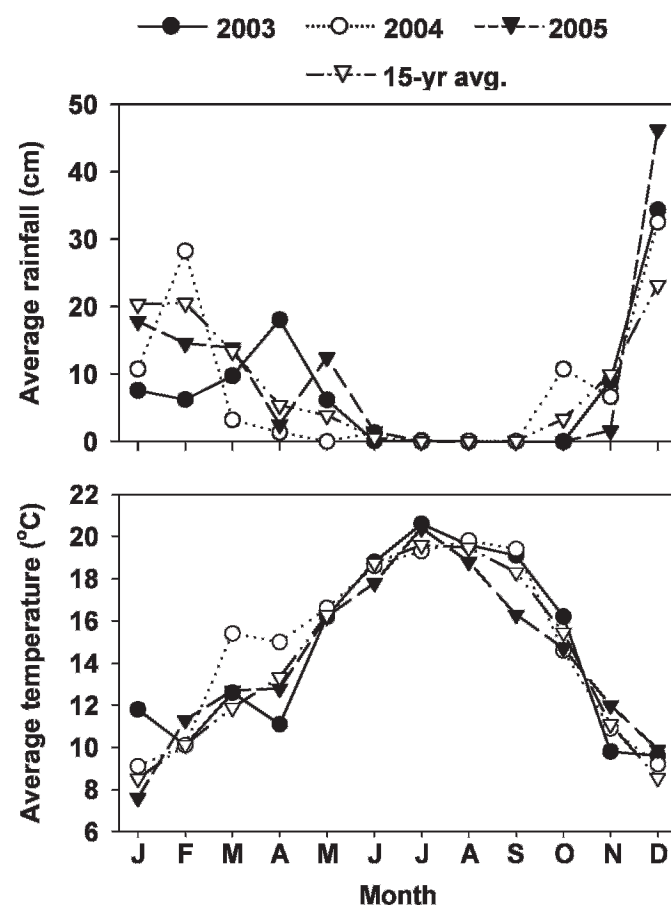

Figure 1. Average monthly rainfall and air temperature during study years (2003 to 2005) and 15-yr averages (1991 to 2005).

one of three *Erodium* species—broadleaf filaree [*Erodium botrys* (Cav.) Bertol.], redstem filaree [*E. cicutarium* (L.) L'Her. ex Ait.], and whitestem filaree [*E. moschatum* (L.) L'Her. ex Ait.]—necessitated combining all *Erodium* biomass measurements into *Erodium* sp. The same situation applied to *Sonchus* plants that shared characteristics of annual sowthistle and spiny sowthistle.

Petioles and soil for analyses of mineral composition were collected at full bloom (June 5, 2003; June 1, 2004; and May 26, 2005). Within each replicate row, 100 petioles were collected by a standard sampling procedure (Winkler et al. 1965), pooled, dried (70 C, 7 d), ground, and analyzed for total nitrogen (N), total phosphorus (P), total potassium (K), zinc (Zn), and boron (B) (DANR Laboratories, University of California, Davis, CA). Soil samples were collected from four random locations with a 4.6-cm-diameter auger to a depth of 15 cm, pooled, dried (70 C, 7 d), ground, and analyzed for NH_4-N, NO_3-N, exchangeable P (X-P), exchangeable K (X-K), exchangeable sodium (X-Na), exchangeable calcium (X-Ca), exchangeable magnesium (X-Mg), cation exchange capacity (CEC), organic matter (OM), and pH. To determine cumulative effects of treatments on soil biological activity, we measured net nitrification and N mineralization, potential N mineralization, and potential microbial respiration (Robertson et al. 1999) on May 26, 2005. Fruit clusters were harvested (September 19, 2003; September 28, 2004; and October 25, 2005) from six adjacent vines per row. Dormant canes were weighed (November 27, 2003; November 22, 2004; and December 12, 2005) from the same vines.

Analyses of variance (ANOVAs) were used to determine the effects of treatment and year on total weed biomass; vine mineral nutrients; soil chemical, physical, and biological properties; grape yields; and pruning weights. Biomass from the four quadrats per treatment per block were averaged. ANOVAs were performed with the use of the MIXED procedure in SAS,[3] with Kenward-Roger as the denominator degrees-of-freedom method (Littell et al. 1996). Year was considered a repeated measure, block and block interactions were random effects, and treatment, year, and treatment by year were fixed effects. To satisfy the assumption of homogeneity of variance, the following transformations were applied: log_{10} transformations to total weed biomass, petiole Zn, soil NH_4-N, soil NO_3-N, and potential microbial respiration; square-root transformations to vine pruning weights and soil X-Na; reciprocal square-root transformations to soil X-K, net N mineralization, and net change in soil N pools; and rank transformations to soil X-Ca, soil X-Mg, soil CEC, and soil pH. For main or interaction effects that were significant ($P < 0.05$), differences among treatment means were assessed by comparison of 95% confidence intervals, such that means without overlapping intervals were considered significantly different (Westfall et al. 1999). Reverse-transformed means and 95% confidence limits are presented, for ease of interpretation.

Canonical correspondence analysis (CCA) was used to evaluate treatment effects on weed community structure (ter Braak 1987). Analysis was based on aboveground biomass of weed species present in ≥ 8% of the samples. Species omitted from the analysis were present in fewer than 4 of 60 total samples collected over the course of the entire experiment and were, thus, uninformative. Treatments were treated as independent variables, species biomass as dependent variables, and years and blocks as covariables. CCA was performed in
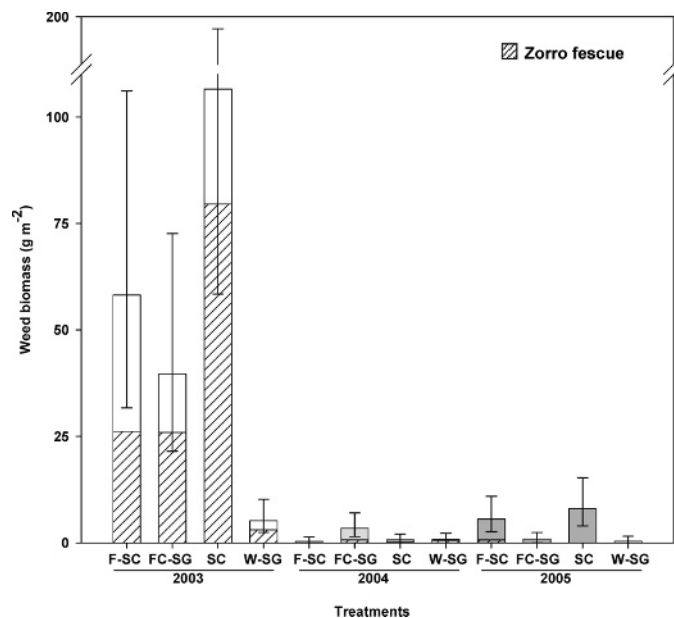

Figure 2. Total weed biomass for the treatment by year interaction. Error bars represent 95% confidence intervals for mean total weed biomass; treatment means with overlapping confidence intervals are not significantly different. Treatment abbreviations are as follows: fall–spring cultivation (F–SC), fall cultivation-spring glyphosate (FC–SG), spring cultivation (SC), and winter-spring glyphosate (W–SG), respectively.

CANOCO,[4] with axis scores centered to interspecies distances and biplot scaling (Leps and Smilauer 2003). Automatic forward selection with Monte Carlo permutation tests was used to determine the significance of the treatments. Treatment centroids and canonical coefficients for the species are presented in biplots. Proximity of a species score to a treatment centroid signifies that the species had the highest relative abundance in that treatment.

Results and Discussion

Treatment Efficacy. Total weed biomass varied significantly among treatments, but relative differences were not consistent among years (treatment by year interaction significant at $P < 0.0001$). In 2003, mean value comparisons for each treatment indicated that winter–spring glyphosate was most effective in reducing weed biomass (Figure 2). In 2005, both glyphosate treatments, winter–spring glyphosate and fall cultivation–spring glyphosate, were equally effective and had significantly lower weed biomass than cultivation alone. In 2004, however, all treatments were equally effective, except for fall cultivation–spring glyphosate. Total weed biomass declined by 10-fold from 2003 to 2004, and remained relatively low in 2005 (Figure 2). Lower weed biomass in all treatments in 2004 may be attributable to a combination of low precipitation (88 cm in October 2003 to June 2004) and unseasonably high temperatures in late winter (Figure 1). Based on mean value comparisons, this was followed by statistically significant increases, albeit slight, in weed biomass in 2005, but only for fall–spring cultivation and spring cultivation (Figure 2); weed biomass in the glyphosate treatments remained low. Regardless, all treatments had 10-fold lower weed biomass in 2005 than in 2003, despite similar rainfall in both years (112 and 113 cm, respectively; Figure 1).

Table 2. Weed species in a California vineyard at peak biomass in 2003–2005.

Species	Common name	Fall–spring cultivation			Fall cultivation–spring glyphosate			Spring cultivation			Winter–spring glyphosate		
		2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005
Anagallis arvensis L.	Scarlet pimpernel	+	−	−	−	+	−	+	−	+	−	−	+
Brassica rapa L.	Birdsrape mustard	+	−	−	−	−	+	−	−	+	−	−	−
Bromus carinatus H. & A.	California brome	−	−	−	−	−	−	−	−	+	−	−	−
Bromus hordeaceus L.	Soft brome	−	−	+	−	−	+	−	−	−	−	−	−
Calendula arvensis L.	Field marigold	−	−	−	−	−	−	+	−	+	−	−	+
Chenopodium album L.	Common lambsquarters	−	+	−	−	−	+	+	−	−	−	−	−
Convolvulus arvensis L.	Field bindweed	−	+	−	−	+	−	−	+	+	−	−	−
Cyperus sp.	Sedge	−	−	−	−	−	−	−	−	−	−	−	+
Epilobium brachycarpum C. Presl	Panicle willowherb	+	−	+	+	+	+	+	−	−	+	+	−
Erodium sp.	Filaree	+	−	+	−	+	+	+	−	+	+	+	+
Festuca idahoensis Elmer	Idaho fescue	−	−	−	−	−	−	−	+	−	−	−	+
Geranium carolinianum L.	Carolina geranium	+	−	+	−	+	+	−	+	+	−	+	+
Gnaphalium purpureum L.	Purple cudweed	+	−	−	−	−	−	−	−	−	−	−	−
Hordeum brachyantherum Nevski	Meadow barley	−	−	+	−	−	−	−	−	+	−	−	−
Kickxia spuria (L.) Dumort.	Female fluvellin	+	−	+	−	+	+	−	+	+	−	−	−
Lactuca serriola L.	Prickly lettuce	−	+	−	−	−	−	−	−	−	−	+	−
Lythrum hyssopifolia L.	Loosestrife	−	−	+	−	+	−	+	−	−	−	−	−
Medicago polymorpha L.	California burclover	−	−	+	−	−	−	−	−	−	−	−	+
Picris echioides L.	Bristly oxtongue	−	−	−	−	−	−	−	−	−	−	+	−
Plantago lancelota L.	Buckhorn plantain	−	−	−	−	−	−	−	−	−	−	+	−
Raphanus raphanistrum L.	Wild radish	−	+	−	−	+	+	−	−	−	−	−	−
Rumex crispus L.	Curly dock	−	−	−	−	+	+	+	−	+	+	+	+
Senecio vulgaris L.	Common groundsel	−	−	−	−	−	−	−	−	−	−	+	+
Sonchus sp.	Sowthistle	+	−	+	−	+	+	−	−	+	−	−	+
Veronica persica Poir.	Persian speedwell	−	−	−	−	−	−	−	−	−	−	+	−
Vitis vinifera L. 'Merlot'	Volunteer grape	+	−	+	+	+	+	−	−	+	−	+	+
Vulpia myuros var. *hirsuta* Hack.	Volunteer zorro fescue	+	+	+	+	+	+	+	+	+	+	+	+

Zorro fescue was especially dominant in 2003 (Figure 2), 8 mo after seeding the vineyard middles with this cover crop. Significant annual changes in total weed biomass may be related, in part, to germination of the cover crop in the rows. Zorro fescue is a strong competitor in California's annual grasslands, due to its rapid germination after the first rains and its ruderal nature (Brown and Rice 2000). Our finding of low weed biomass in all treatments in 2005, despite high rainfall, suggests that either the climate of the 2004 rainy season had persistent impacts on subsequent weed establishment or that the dwindling biomass of zorro fescue reduced its contribution to total weed biomass over the course of the study.

Our finding of low weed biomass with two glyphosate applications per year indicates that this herbicide is more effective than cultivation at reducing total weed biomass. However, given that two passes with the Clemens cultivator further decreased weed biomass relative to one pass (Figure 2), it is possible that the level of control achieved with two glyphosate applications may be matched through additional cultivation passes. Pairing fall cultivation with glyphosate was as effective at reducing weed biomass as two glyphosate applications in 2004 and 2005, suggesting that substituting a glyphosate application with cultivation, instead of using two glyphosate applications per year, may be an effective method of reducing herbicide use in vineyards.

Weed Communities. CCA revealed significant community differences among treatments. The species present in the communities fell into one of three categories: (1) ubiquitous among treatments (e.g., zorro fescue); (2) sporadically present in a given treatment [e.g., California brome (*Bromus carinatus* H. & A.)]; or (3) dominant in certain treatments [e.g., California burclover (*Medicago polymorpha* L.)]. Zorro fescue was present in all treatments and years (Table 2); hence its

position at the origin of the biplot (Figure 3). The three most common species in 2003, 2004, and 2005, respectively, were (followed by ranges of relative proportions of biomass per block in parentheses): zorro fescue, panicle willowherb (*Epilobium brachycarpum* C. Presl), and sowthistle (*Sonchus* sp.) (75 to 100%); zorro fescue, Carolina geranium (*Geranium carolinianum* L.), and curly dock (*Rumex crispus* L.) (24 to 63%); and filaree (*Erodium* sp.), Carolina geranium, and sowthistle (15 to 65%).

The weed community associated with spring cultivation was distinct from that of all other treatments, based on its opposite position on axis 1, which was the only axis that significantly explained community differences among treatments (P = 0.05; Figure 3). Spring cultivation had the highest relative abundances of California burclover and sowthistle species. Scarlet pimpernel (*Anagallis arvensis* L.) and field bindweed were also most abundant in spring cultivation, albeit at much lower biomass than California burclover and sowthistle species. Scarlet pimpernel was relatively abundant in both spring cultivation and fall–spring cultivation, which is reflected by the proximity of this species' biplot score to both treatments.

Based on the high relative abundance of scarlet pimpernel, field bindweed, and sowthistle species resulting from spring cultivation in 2 of 3 study years, it is possible that either the presence of soil disturbance or the absence of herbicides shifts the vineyard weed community to these species. Field bindweed and sowthistle species are considered problematic in vineyards because they grow into the vine canopy and interfere with harvest (Lanini and Bendixen 1992). It is possible that the high relative abundance of field bindweed in cultivated rows is due to dispersal of its rhizomes by the Clemens cultivator, unlike in previous studies that reported a decrease in this species' frequency with deeper cultivation by
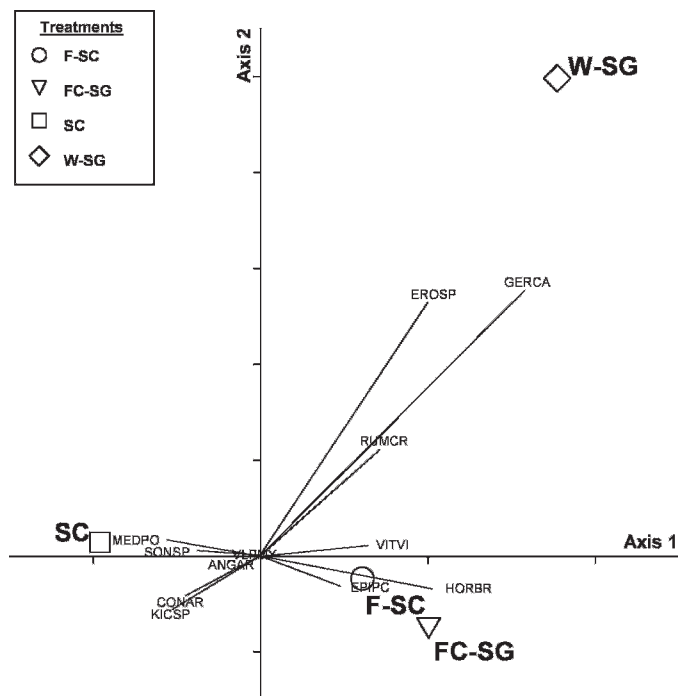
Figure 3. Species–treatment biplot from canonical correspondence analysis of weed communities in the four treatments. The circle, triangle, square, and diamond represent fall–spring cultivation (F–SC), fall cultivation–spring glyphosate (FC–SG), spring cultivation (SC), and winter–spring glyphosate (W-SG), respectively. Bayer codes represent the following species: Scarlet pimpernel (ANGAR), field bindweed (CONAR), panicle willowherb (EPIPC), filaree species (EROSP), Carolina geranium (GERCA), meadow barley (HORBR), female fluvellin (KICSP), California burclover (MEDPO), curly dock (RUMCR), sowthistle species (SONSP), volunteer grape (VINVI), and volunteer zorro fescue (VLPMY). Axis 1: $P = 0.05$, $\lambda = 0.21$, species–environment correlation = 0.75; axis 2: $P = 0.14$, $\lambda = 0.15$, species–environment correlation = 0.61 (sum of all canonical eigenvalues is 0.38).

mouldboard plows that likely buried the rhizomes (Froud-Williams 1988). Our finding of a high relative abundance of sowthistle species in spring-cultivated rows and a concomitant low relative abundance in the glyphosate-only treatment is supported by similar results from annual cropping systems by Critchley et al. (2006) and Puricelli and Tuesca (2005). Sensitivity of California burclover to glyphosate has also been documented (Wallace et al. 1998).

The weed community associated with fall–spring cultivation was more similar to that of fall cultivation–spring glyphosate than to spring cultivation (Figure 3). Fall cultivation was associated with high relative abundances of panicle willowherb and volunteer grape, in the years these two species were present (Table 2), regardless of the type of practice (cultivation or glyphosate) that followed in spring. Female fluvellin [*Kickxia spuria* (L.) Dumort.] and volunteer grape were also associated with fall cultivation, albeit at much lower biomass than panicle willowherb. Panicle willowherb is a problematic vineyard weed because of its height. In contrast, volunteer grape rarely becomes established in California vineyards, which is likely due to their susceptibility to *Daktulosphaira vitifoliae* (Fitch) (grape phylloxera), a widespread pest that necessitates grafting wine grape cultivars on phylloxera-resistant rootstocks (Granett et al. 2001). Meadow barley (*Hordeum brachyantherum* Nevski), present only in 2005 (Table 2), was most abundant in fall–spring cultivation.

Although treatment centroids from both fall cultivation treatments grouped close to meadow barley (Figure 3), this species was absent from fall cultivation–spring glyphosate (Table 2).

Based on high relative abundances of filaree species and curly dock in winter–spring glyphosate in all study years (Figure 3), it is possible that repeated glyphosate use shifts the vineyard weed community to these species. Of the three, curly dock is most problematic in vineyards because of its perennial nature and tall shoots (Lanini and Bendixen 1992). Given that filaree and curly dock germinate in the rainy season (DiTomaso and Healy 2007), their dominance in the glyphosate-only treatment, coupled with their contrasting low biomass in fall cultivation–spring glyphosate, suggest that they were well established before the winter application of glyphosate in the glyphosate-only treatment. Our findings are consistent with those of Young (2004), who found that broadleaf filaree and curly dock were only partially controlled by glyphosate a week after treatment, possibly due to their dominant tap roots, which may enhance their tolerance to glyphosate and/or increase their susceptibility to damage by the Clemens cultivator.

There was a significant effect of the treatment by year interaction on weed species richness ($P = 0.02$), but mean comparisons showed no significant differences among treatments (data not shown). Neither species diversity nor evenness varied significantly among treatments ($P = 0.7$ and $P = 0.07$, respectively) or years ($P = 0.07$ and $P = 0.5$, respectively). We expected the treatments to influence species diversity, richness, and evenness differentially, given that herbicides have been shown to have greater effects on diversity than tillage in other systems (Legere and Samson 2004; VanGessel et al. 2004). The lack of significant treatment effects may be attributed to the low number of weed control attempts in our treatments. Also, the Clemens cultivator is less physically disruptive to soil than tillage implements (e.g., mouldboard or chisel plows) used in other studies (Critchley et al. 2006; Legere et al. 2005).

Impacts on Production. There were no significant differences in yield due to treatment ($P = 0.1$), year ($P = 0.5$), or their interaction ($P = 0.4$). Average yield across years and treatments was 6.5 kg vine^{-1} ($n = 12$). Pruning weights varied significantly among years ($P = 0.003$), with the highest measured in 2005, at 0.7 kg vine^{-1} ($n = 4$), and the lowest in 2004, at 0.6 kg vine^{-1} ($n = 4$). There were no significant differences in pruning weights due to treatment ($P = 0.1$) or the treatment by year interaction ($P = 0.7$).

Petiole K was the only mineral nutrient that was significantly affected by the treatments, based on ANOVA (Table 3). Vines in fall–spring cultivation had the lowest concentrations of total K compared with that of winter–spring glyphosate (15.5 mg vs. 17.4 mg). However, overlapping 95% confidence intervals among all four treatment means signified that they were not significantly different (data not shown). Petiole N, K, and Zn varied significantly among years, but not treatments (Table 3). Changes in petiole P and B over time were not consistent among treatments, hence the significant treatment by year interaction, but means comparisons following ANOVA showed no significant differences among treatments within years (data not shown). Annual means averaged across treatments ($n = 4$ per year) ranged

Table 3. Analysis of variance of grapevine (petiole) and soil mineral nutrition parameters, and soil physical properties under the influence of four weed control treatments, from 2003–2005.

Parameters	P values		
	Treatment (T)	Year (Y)	T by Y
Petiole nutrients			
Total N	0.4349	< 0.0001	0.0988
Total P	0.5865	< 0.0001	0.0173
Total K	0.0304	< 0.0001	0.0565
B	0.5598	< 0.0001	0.0187
Zn	0.4985	< 0.0001	0.1276
Soil nutrients			
NH_4-N	0.0122	< 0.0001	0.3564
NO_3-N	0.2487	< 0.0001	0.5302
Olsen P	0.9403	0.5533	0.4200
X-K	0.4279	0.4643	0.9532
X-Na	0.3927	< 0.0001	0.5240
X-Ca	0.9527	0.1143	0.1384
X-Mg	0.7790	0.1897	0.0128
Soil physical properties			
CEC	0.1700	0.1967	0.0630
OM	0.1303	0.7445	0.4272
pH	0.6596	0.0740	0.7931

from 8 to 11 mg total N, 7 to 8 mg total P, 13 to 20 mg total K, 41 to 45 µg B, and 91 to 364 µg Zn g^{-1} dry petiole.

Soil NH_4-N was the only soil parameter that was significantly affected by the treatments, based on ANOVA (Table 3). Soil NH_4-N in spring cultivation was highest, at 7.5 µg, compared to the lowest concentration of 5.8 µg in fall cultivation–spring glyphosate. However, overlapping 95% confidence intervals among all four treatment means signified that they were not significantly different (data not shown). Soil NO_3-N, NH_4-N, and X-Na varied significantly among years, but not treatments (Table 3). Changes in X-Mg over time were not consistent among treatments, hence the significant treatment by year interaction, but means comparisons following ANOVA showed no significant differences among treatments within years (data not shown). Annual means averaged across treatments ($n = 4$ per year) ranged from 4 to 13 µg NH_4-N, 3 to 10 µg NO_3-N, 20 to 22 µg Olsen P, 7.4 to 7.8 µmol X-K, 1.8 to 2.2 µmol X-Na, 130 to 138 µmol X-Ca, 122 to 127 µmol X-Mg, 378 to 389 µmol cation exchange capacity, and 23.8 to 24.1 mg organic matter g^{-1} dry soil, and 5.7 to 5.9 pH. ANOVAs of soil microbial activity, assessed in 2005, showed no treatment effects on net nitrification and N mineralization, potential N mineralization, or potential microbial respiration (data not shown). Potential N mineralization also tended to be higher in the cultivation treatments (15 to 34 µg NH_4-N g^{-1} 7 d^{-1}) versus winter–spring glyphosate (8 µg NH_4-N g^{-1} 7 d^{-1}).

Given that neither vine yield nor growth were affected by the treatments, it seems that one or two Clemens cultivations per year are unlikely to harm grapevines, at least under soil conditions similar to that of our study site. Lower-petiole K in cultivated rows was within adequate levels (> 15 mg g^{-1} at bloom; Christensen et al. 1978). Higher NH_4-N in spring cultivated soils was likely due to the short time (1–3 wk) between cultivation and sampling; we detected the ephemeral increase in soil NH_4-N that follows incorporation of plant material (Jackson 2000). Given that treatments with cultivation had both higher weed biomass and displayed trends toward higher soil microbial activity than the glyphosate-only treatment, it seems that incorporation of weed biomass influenced changes in soil N availability, thereby enhancing soil biological processes. No change in soil microbial respiration due to cultivation was observed, despite past reports of negative effects of tillage (Calderón et al. 2000). This may be due to the shallow soil disturbance from the Clemens cultivator, whereas more intensive tillage implements bring about significant reductions in microbial respiration (Franzluebbers et al. 1999).

Management Implications. Given that vine yield, growth, and nutrition were unaffected by the high weed biomass in the low-efficacy, spring cultivation treatment, it seems that weed growth poses a minor threat to wine grape yields, at least in the drip-irrigated, northern California vineyard we examined. However, this treatment was associated with the highest relative abundance of field bindweed and sowthistle species. These are problematic vineyard weeds due to their habit of growing into the vine canopy, where their presence slows canopy management practices and harvest, all of which are typically done by hand. With respect to weed community composition, our findings of differential species responses to the treatments are consistent with those of past research in annual cropping systems, which show that frequency, timing, and tolerance of cultivation or herbicides interact to have varied effects on weed species (e.g., Baylis 2000; Critchley et al. 2006; Legere and Samson 2004; Poggio 2005). Although we limited our assessment of weed biomass and composition to the end of the rainy season, when vineyard weeds are most abundant, there is a need for additional work on seasonal weed community dynamics. The lack of treatment effects on yield, growth, and mineral nutrition parameters in all 3 study years suggests that changes in weed biomass or species composition that may have occurred after we sampled weed biomass did not impact production. Nonetheless, detailed knowledge of when the most problematic vineyard weeds become established and senesce, information that is not currently available, is crucial for developing more sustainable weed control practices.

Sources of Materials

Acknowledgments

Literature Cited

Agamalian, H.S. 1992. Vegetation Management Guidelines. Pages 326–330 *in* D.L. Flaherty, L.P. Christensen, W.T. Lanini, J.J. Marois, P.A. Phillips, and L.T. Wilson, eds. Grape Pest Management. 2nd ed. Oakland, CA: University of California, Division of Agriculture and Natural Resources, Publication No. 3343.

Anonymous. 2006a. The California Water Plan Update. Sacramento, CA: California Department of Water Resources Bulletin 160-05. http://www.waterplan.water.ca.gov. Accessed September 28, 2006.

Anonymous. 2006b. Noncitrus Fruits and Nuts 2005 Summary. Washington, DC: United States Department of Agriculture, Agricultural Statistics Service.

Basu, C., M.D. Halfill, T.C. Mueller, and C.N.J. Stewart. 2004. Weed genomics: new tool to understand weed biology. Trends Plant Sci. 9:391–398.

Baylis, A.D. 2000. Why glyphosate is a global herbicide: strengths, weaknesses and prospects. Pest Manag. Sci. 56:299–308.

Brown, C.S. and K.J. Rice. 2000. The mark of Zorro: Effects of the exotic annual grass *Vulpia myuros* on California native perennial grasses. Restor. Ecol. 8:10–17.

Buhler, D.D. 2002. Challenges and opportunities for integrated weed management. Weed Sci. 50:273–280.

Calderón, F.J., L.E. Jackson, K.M. Scow, and D.E. Rolston. 2000. Microbial responses to simulated tillage in cultivated and uncultivated soils. Soil Biol. Biochem. 32:1547–1559.

Cardina, J., C.P. Herms, and D.J. Doohan. 2002. Crop rotation and tillage system effects on weed seedbanks. Weed Sci. 50:448–460.

Cardina, J., T.M. Webster, C.P. Herms, and E.E. Regnier. 1999. Development of weed IPM: levels of integration for weed management. J. Crop Prod. 2:239–267.

Christensen, L.P., A.N. Kasimatis, and F.L. Jensen. 1978. Grapevine Nutrition and Fertilization in the San Joaquin Valley. Oakland, CA: University of California, Agriculture and Natural Resources.

Critchley, C.N.R., J.A. Fowbert, and A.J. Sherwood. 2006. The effects of annual cultivation on plant community composition of uncropped arable field boundary strips. Agric. Ecosyst. Environ. 113:196–205.

DiTomaso, J.M. and E.A. Healy. 2007. Weeds of California and Other Western States. Volume 2. Geraniaceae–Zygophyllaceae. Oakland, CA: University of California, Division of Agriculture and Natural Resources, Publication No. 3488.

Franzluebbers, A.J., G.W. Langdale, and H.H. Schomberg. 1999. Soil carbon, nitrogen, and aggregation in response to type and frequency of tillage. Soil Sci. Soc. Am. J. 63:349–355.

Froud-Williams, R.J. 1988. Changes in weed flora with different tillage and agronomic management systems. Pages 213–236 *in* M.A. Altieri and M. Liebman, eds. Weed Management in Agroecosystems: Ecological Approaches. Boca Raton, FL: CRC.

Granett, J., M.A. Walker, L. Kocsis, and A.D. Omer. 2001. Biology and management of grape phylloxera. Ann. Rev. Entomol. 46:387–412.

Green, C. and A. Kremen. 2003. U.S. Organic Farming in 2000–2001: Adoption of Certified Systems, Agriculture Information Bulletin No. 780. Washington, DC: United States Department of Agriculture, Economic Research Service. http://www.ers.usda.gov/publications/aib780/. Accessed September 28, 2006.

Jackson, L.E. 2000. Fates and losses of nitrogen from a nitrogen-15-labeled cover crop in an intensively managed vegetable system. Soil Sci. Soc. Am. J. 64:1404–1412.

Kadir, S. and K. Al-Khatib. 2006. Weed control in grape after fall and spring application of selected herbicides. Weed Technol. 20:74–80.

Klonsky, K. 2004. Organic Agricultural Production in California. Pages 241–256 *in* J. Siebert, ed. California Agriculture: Dimensions and Issues. Oakland, CA: Giannini Foundation, University of California Press.

Lanini, W.T. and W.E. Bendixen. 1992. Characteristics of Important Vineyard Weeds. Pages 321–325 *in* D.L. Flaherty, L.P. Christensen, W.T. Lanini, J.J. Marois, P.A. Phillips, and L.T. Wilson, eds. Grape Pest Management. 2nd ed. Oakland, CA: University of California, Division of Agriculture and Natural Resources, Publication No. 3343.

Legere, A. and N. Samson. 2004. Tillage and weed management effects on weeds in barley–red clover cropping systems. Weed Sci. 52:881–885.

Legere, A., K.L. Stevenson, and D.L. Benoit. 2005. Diversity and assembly of weed communities: contrasting responses across cropping systems. Weed Res. 45:303–315.

Leps, J. and P. Smilauer. 2003. Multivariate Analysis of Ecological Data using CANOCO. Cambridge, United Kingdom: Cambridge University Press.

Liebman, M. and E.R. Gallandt. 1997. Many Little Hammers: Ecological Approaches for Management of Crop–Weed Interactions. Pages 291–343 *in* L.E. Jackson, ed. Ecology in Agriculture. San Diego: Academic.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS System for Mixed Models. Cary, NC: SAS Institute.

Menalled, F.D., K.L. Gross, and M. Hammond. 2001. Weed aboveground and seedbank community responses to agricultural management systems. Ecol. Appl. 11:1586–1601.

Monteiro, A. and I. Moreira. 2004. Reduced rates of residual and post-emergence herbicides for weed control in vineyards. Weed Res. 44:117–128.

Poggio, S.L. 2005. Structure of weed communities occurring in monoculture and intercropping of field pea and barley. Agric. Ecosyst. Environ. 109:48–58.

Puricelli, E. and D. Tuesca. 2005. Weed density and diversity under glyphosate-resistant crop sequences. Crop Protect. 24:533–542.

Robertson, G.P., D. Wedin, P.M. Groffman, J.M. Blair, E.A. Holland, K.J. Nadelhoffer, and D. Harris. 1999. Soil Carbon Availability: Nitrogen Mineralization, Nitrification, and Soil Respiration potentials. Pages 258–271 *in* G.P. Robertson, D.C. Coleman, C.S. Bledsoe, and P. Sollins, eds. Standard Soil Methods for Long-Term Ecological Research. New York: Oxford University Press.

Shrestha, A., S.Z. Knezevic, R.C. Roy, B.R. Ball-Coelho, and C.J. Swanton. 2002. Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. Weed Res. 42:76–87.

ter Braak, C.J.F. 1987. Ordination. Pages 91–169 *in* R.H.G. Jongman, C.J.F. t. Braak, and O.F.R. v. Tongeren, eds. Data Analysis in Community and Landscape Ecology. Wageningen, The Netherlands: Centre for Agricultural Publishing and Documentation.

VanGessel, M.J., D.R. Forney, M. Conner, S. Sankula, and B.A. Scott. 2004. A sustainable agriculture project at Chesapeake Farms: a six-year summary of weed management aspects, yield, and economic return. Weed Sci. 52:886–896.

Wallace, A., R.A. Lancaster, and N.L. Hill. 1998. Application of non-selective herbicides during flowering of pasture legumes can reduce seed yield and alter seed characteristics. Aust. J. Exp. Agric. 38:583–594.

Westfall, P.H., R.D. Tobias, D. Rom, R.D. Wolfinger, and Y. Hochberg. 1999. Multiple Comparisons and Multiple Tests. Cary, NC: SAS Institute.

Willer, H. and R. Zanoli. 2000. Organic viticulture in Europe. Pages 23–29 *in* H. Willer and U. Meir, eds. Proceedings of the International Congress on Organic Viticulture. Basel, Switzerland.

Winkler, A.J., J.A. Cook, W.M. Kliewer, and L.A. Lider. 1965. General Viticulture. Berkeley, CA: University of California Press.

Young, S.L. 2004. Natural product herbicides for control of annual vegetation along roadsides. Weed Technol. 18:580–587.